An Interferometer for Low Uncertainty Vector Metrology

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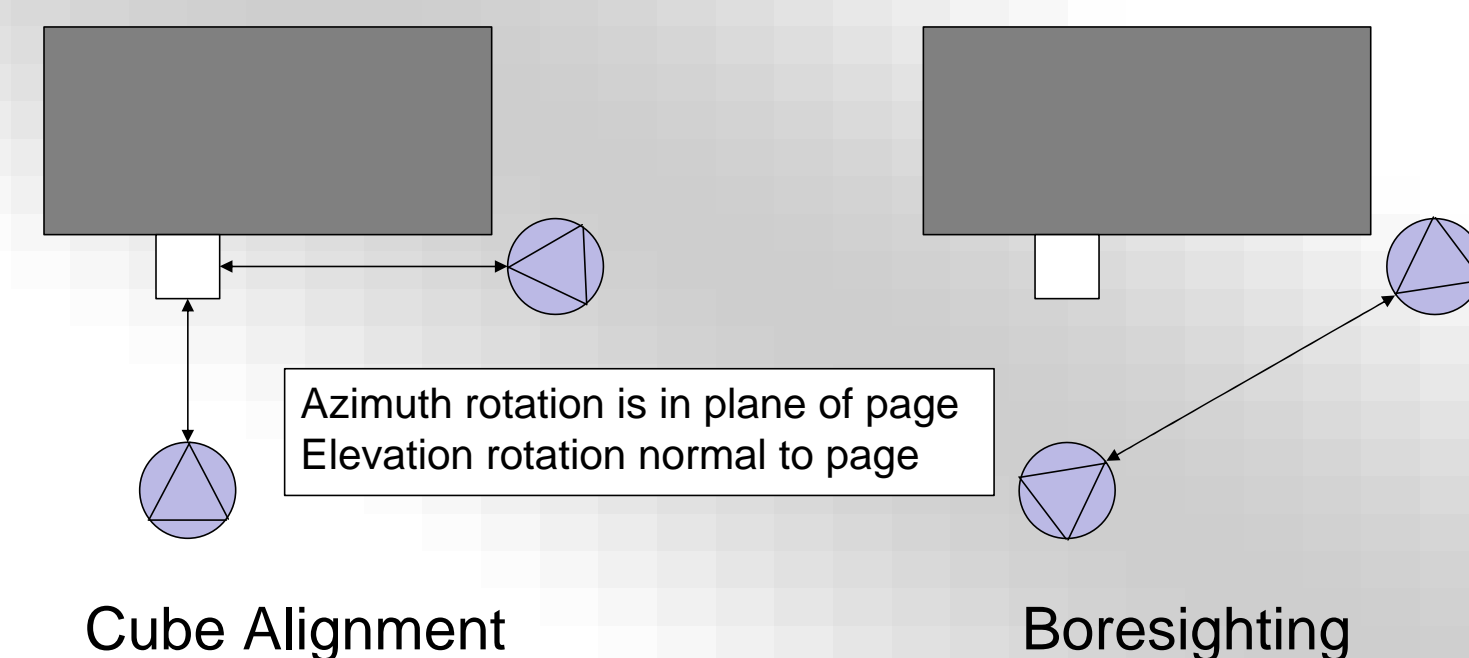
What is Vector Metrology?

Vector metrology is the measurement system used to determine the orientation and envelope of critical components on space flight hardware.   This system utilizes instruments such as theodolites and mirrored alignment cubes to acquire measurements for constructing a spacecraft coordinate system.

The Measurement Process

1. Alignment cubes are bonded to a test surface
2. The normal to the cube face is measured with a theodolite
   a. The theodolite projects a collimated crosshair onto cube face
   b. The theodolite is aligned to the cube face normal using the return from cube
3. Theodolites at different locations are boresighted to build a coordinate system

Azimuth rotation is in plane of page
Elevation rotation normal to page

Cube Alignment   Boresighting

Background

Vector metrology plays a vital role in the assembly of space instrumentation and spacecraft. A primary use of this technology is analysis of environmental testing on spacecraft components and hardware (vibration, thermal vacuum, etc.). Before and after each test, the precise orientations of major components are determined. Any discrepancies in these data sets indicate misalignment as a result of the environmental test. Other uses of this measurement system include flight optical instrumentation, the relation of a detector to a mirror, the placement of an optical bench inside an enclosure, and accounting for the deflection of a weighted structure under gravity. Science goals and mechanical tolerances are both made possible by the measurements conducted with theodolites, tilt levels, and laser trackers.

Enabling Technologies

Encoder Discs: Invented by Doug Leviton (Code 551) – Provide position readout with a resolution of 0.02 arcseconds

ABTech Air Bearings: Provide virtually frictionless, stable rotation that is required for sensitive measurements
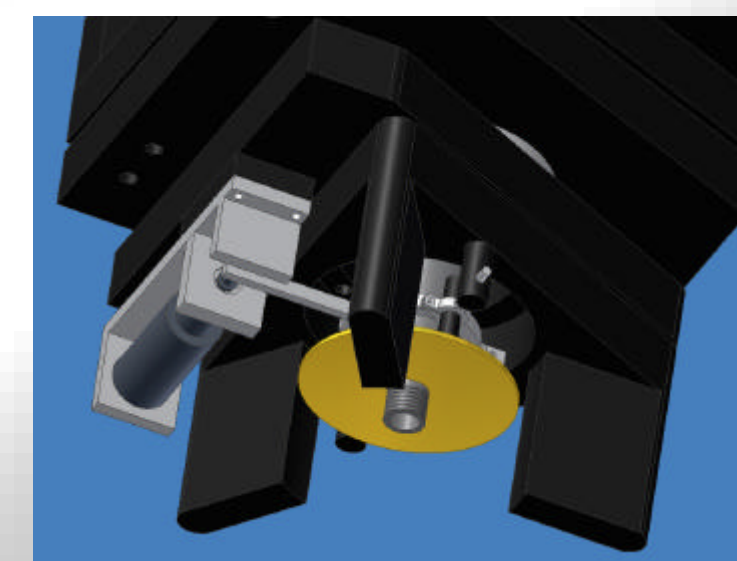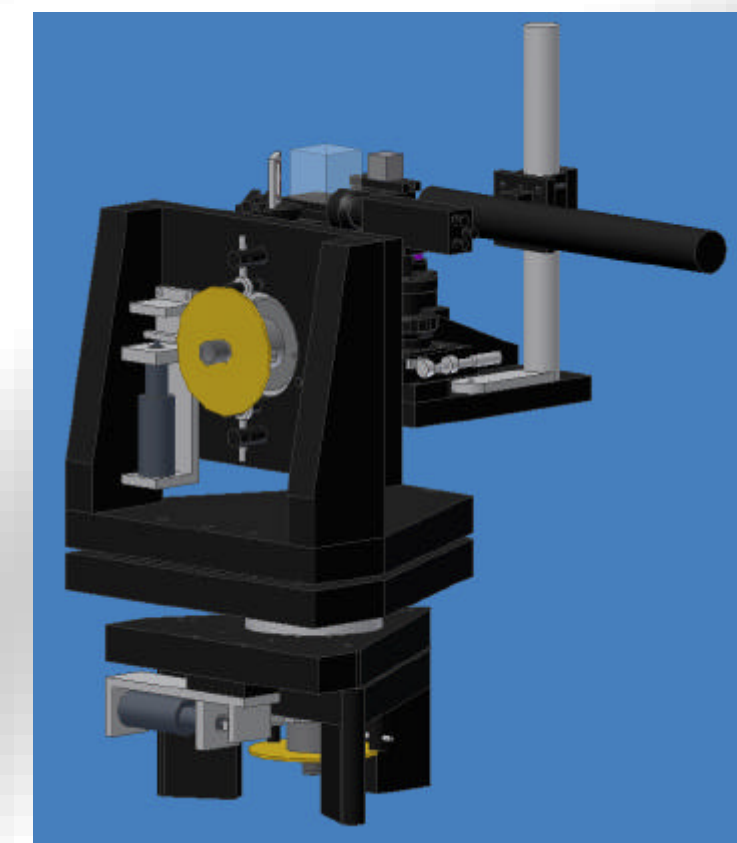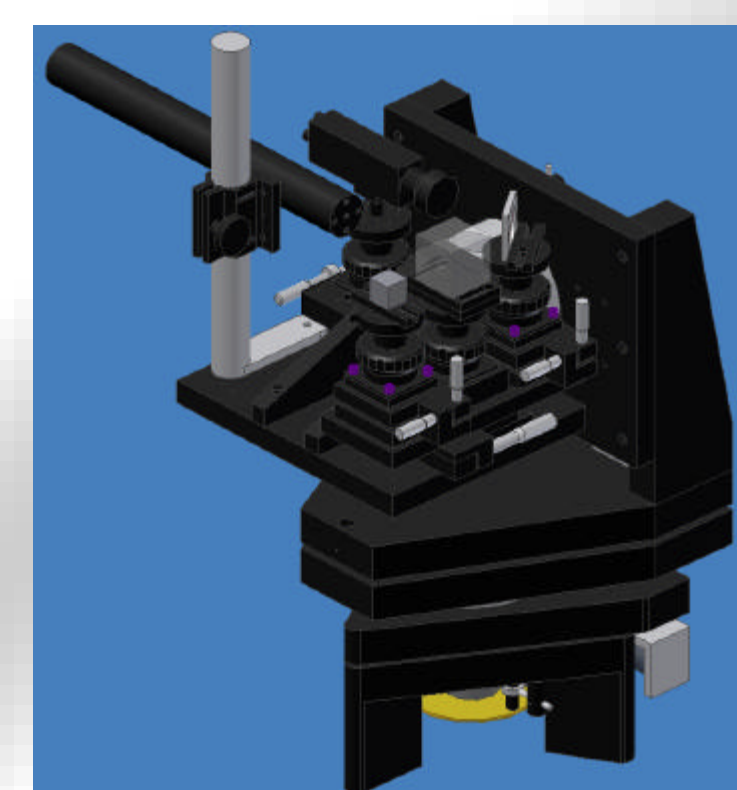
Theodolites and Their Limitations

- A theodolite is a telescope mounted on axes such that it can be rotated in both a vertical and horizontal circle.
- A 360⁰ readout is mated to both the horizontal and vertical axes, allowing the pointing directions of the telescope to be defined in elevation and azimuth.

Limitations

- Recent projects (JWST/ISIM, FKSI, L2EASI) have called for metrology requirements as low as 0.1 arcseconds; however, theodolites have uncertainties of approximately +/- 2 arcseconds.
- Theodolite limitations include imperfections of optical components, leveling capabilities, and the human eye, which is used for alignment.

Theoferometer Design

Azimuth Bearing Assembly: An ABTech air bearing is mounted to a tip-tilt plate which allows alignment of the rotation axis with the gravity vector. A moment arm is attached to a bearing extrusion and manipulated by a Burleigh inchworm motor, which provides better than 0.1 arcsecond resolution. An encoder disc mounted to the bearing extrusion provides precise position readout

Elevation Bearing Assembly: An ABTech air bearing is mounted to a vertical mounting plate attached to a one-DOF tip plate, which allows alignment of the elevation rotation axis perpendicular to the gravity vector. An inchworm motor and encoder disc identical to the azimuth bearing assembly allow fine resolution positioning and position readout.

Interferometer: The interferometer consists of a laser, a CCD camera, an alignment cube, a beam splitter, a mirror and various translation stages, tip-tilt stages and other alignment mechanisms, which are necessary for precise alignment of the other components. Proper optical alignment is essential for beam recombination resulting in interference fringes. The interferometer has 120⁰ of rotation, approximately 60⁰ on either side of its level position.

Each component of the full assembly is modeled and/or designed using Autodesk Inventor.   The components can then be pieced together to check for compatibility before creating final drawings.   The images on the left show the full assembly of the theoferometer.   The images on the right are of actual components that have been made from the Inventor drawings.

Theoferometer model viewed from three different angles
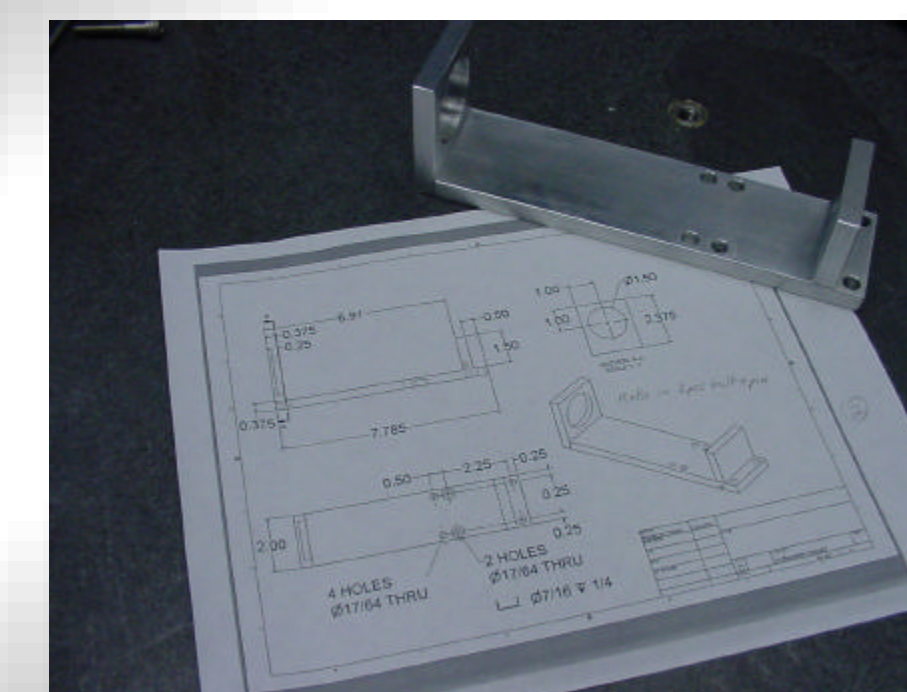
Left: Inchworm motor mount and its associated drawing
Right: Full inchworm mount with moment arm
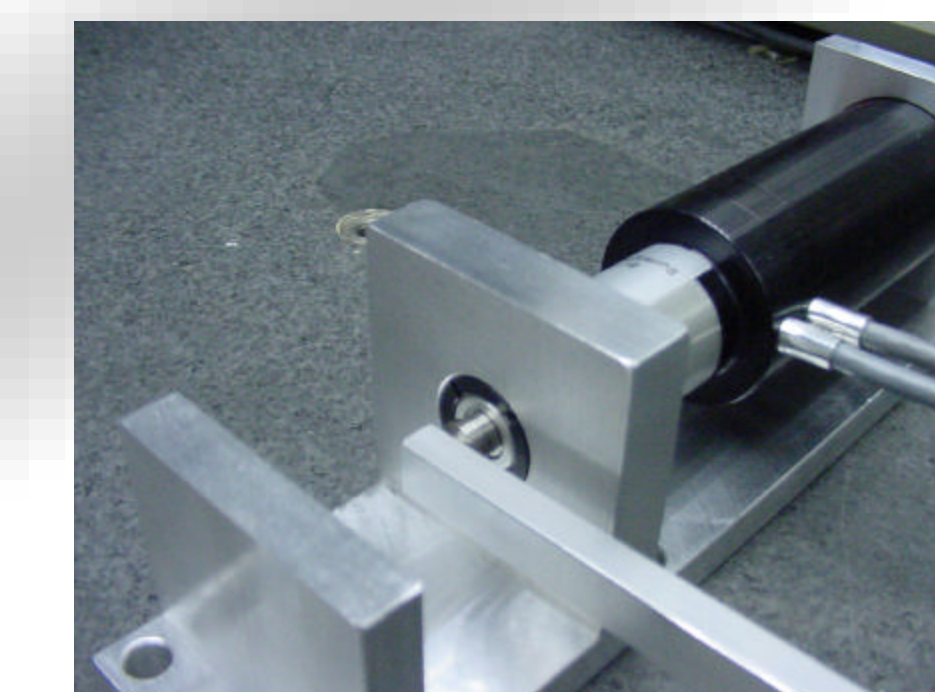
Achieving Low Uncertainty Through Interferometry

An unequal path interferometer can replace the theodolite as the primary tool for vector metrology. A theoferometer consists of a frequency stabilized laser (300m coherence length), and two alignment cubes. One cube serves as the reference and the other, which is attached to the spacecraft, provides the test surface. The combined beams are focused onto a CCD camera, and fringe analysis tells the user how far out of alignment the two systems are at the sub-arcsecond level. An arbitrary fringe pattern is chosen as the alignment criterion. When the interferogram matches this pattern, the orientation of the test cube face can be determined. Azimuth and elevation encoders calibrated to the laser pointing direction provide the same information as a theodolite aligned to the cube.

Reference Alignment Cube
Test Alignment Cube
Stabilized Laser
Beam Splitter
CCD Camera
Fold Mirror

Theoferometer Schematic
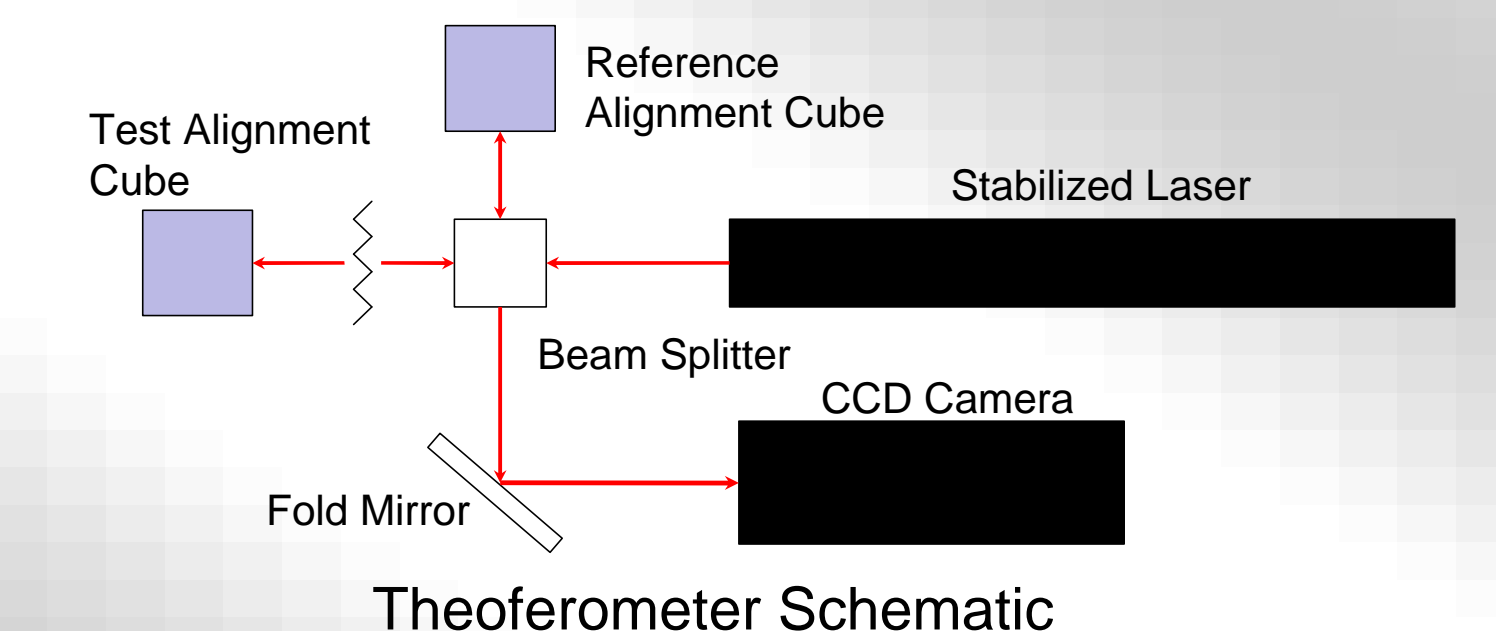
Advantages

- The potential uncertainty of the proposed theoferometer is 0.01 arcsecs or 2 orders of magnitude better than the current technology
- Computer controlled fringe analysis and alignment eliminates human error
- Theoferometers are virtually interchangeable with theodolites so little retraining is required

Project Status

- Full assembly has been drawn in Autodesk Inventor
- All CAD drawings have been submitted to machinists
- All necessary parts have been ordered
- A Visual Basic control interface is being design to consolidate control of inchworms, CCD camera encoder disc read heads, and fringe analysis software
- Physical construction of the theoferometer is beginning as machinists complete parts

Acknowledgements